We claim:

1. A method of forming a lubricious outer surface comprising chromium, said method comprising:

providing a substrate comprising a surface comprising chromium, said surface having an initial coefficient of friction in an unlubricated condition against a steel counterface; and

treating said substrate with an additive comprising an element X under conditions effective to produce a mixture comprising chromium-X molecules and molecules of said substrate adjacent to said lubricious outer surface, wherein said lubricious outer surface comprises a sufficient quantity of said chromium-X molecules to produce a final coefficient of friction in an unlubricated condition against a steel counterface that is less than said initial coefficient of friction of said surface,

said additive being selected from the group consisting of

substituted or unsubstituted metal carbonyls comprising a metal selected from the group consisting of tungsten, molybdenum, chromium, iron, and nickel, wherein said substituted carbonyls comprise an oxygen of the carbonyl substituted by an element selected from the group consisting of X; and

compounds having the general formula

$$H_nC_mX_o$$

wherein

n is from about 0 to about 6;

m is from about 1 to about 2;

o is from about 1 to about 2; and,

X is selected from the group consisting of fluorine, oxygen, sulfur, and chlorine.

2. The method of claim 1 wherein X is fluorine.

3. The method of claim 1 wherein X is sulfur.

4. The method of claim 1 wherein X is chlorine.

5. The method of claim 1 wherein said final coefficient of friction is about 0.3 or less.

6. The method of claim 1 wherein said final coefficient of friction is about 0.2 or less.

7. The method of claim 1 wherein said final coefficient of friction is about 0.1 or less.

8. The method of claim 1 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

9. The method of claim 1 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

10. The method of claim 2 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

11. The method of claim 2 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

12. The method of claim 3 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

13. The method of claim 3 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

14. The method of claim 4 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

15. The method of claim 4 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

16. The method of claim 1 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

17. The method of claim 2 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

18. The method of claim 3 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

19. The method of claim 4 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

20. The method of claim 5 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

21. The method of claim 6 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

22. The method of claim 7 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

23. The method of claim 16 wherein said final hardness is about 15 GPa or more.

24. The method of claim 16 wherein said final hardness is about 20 GPa or more.

25. The method of claim 16 wherein said final hardness is about 25 GPa or more.

26. The method of claim 17 wherein said final hardness is about 15 GPa or more.

27. The method of claim 17 wherein said final hardness is about 20 GPa or more.

28. The method of claim 17 wherein said final hardness is about 25 GPa or more.

29. The method of claim 18 wherein said final hardness is about 15 GPa or more.

30. The method of claim 18 wherein said final hardness is about 20 GPa or more.

31. The method of claim 18 wherein said final hardness is about 25 GPa or more.

32. The method of claim 19 wherein said final hardness is about 15 GPa or more.

33. The method of claim 19 wherein said final hardness is about 20 GPa or more.

34. The method of claim 19 wherein said final hardness is about 25 GPa or more.

35. The method of claim 20 wherein said final hardness is about 15 GPa or more.

36. The method of claim 20 wherein said final hardness is about 20 GPa or more.

37. The method of claim 20 wherein said final hardness is about 25 GPa or more.

38. The method of claim 21 wherein said final hardness is about 15 GPa or more.

39. The method of claim 21 wherein said final hardness is about 20 GPa or more.

40. The method of claim 21 wherein said final hardness is about 25 GPa or more.

41. The method of claim 22 wherein said final hardness is about 15 GPa or more.

42. The method of claim 22 wherein said final hardness is about 20 GPa or more.

43. The method of claim 22 wherein said final hardness is about 25 GPa or more.

44. The method of claim 2 wherein said final coefficient of friction is about 0.3 or less.

45. The method of claim 2 wherein said final coefficient of friction is about 0.2 or less.

46. The method of claim 2 wherein said final coefficient of friction is about 0.1 or less.

47. The method of claim 2 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

48. The method of claim 2 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

49. The method of claim 29 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

50. The method of claim 29 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

51. The method of claim 30 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

52. The method of claim 30 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

53. The method of claim 31 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

54. The method of claim 31 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

55. The method of claim 44 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

56. The method of claim 45 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

57. The method of claim 46 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

58. The method of claim 55 wherein said final hardness is about 15 GPa or more.

59. The method of claim 55 wherein said final hardness is about 20 GPa or more.

60. The method of claim 55 wherein said final hardness is about 25 GPa or more.

61. The method of claim 56 wherein said final hardness is about 15 GPa or more.

62. The method of claim 56 wherein said final hardness is about 20 GPa or more.

63. The method of claim 56 wherein said final hardness is about 25 GPa or more.

64. The method of claim 57 wherein said final hardness is about 15 GPa or more.

65. The method of claim 57 wherein said final hardness is about 20 GPa or more.

66. The method of claim 57 wherein said final hardness is about 25 GPa or more.

67. The method of claim 3 wherein said final coefficient of friction is about 0.3 or less.

68. The method of claim 3 wherein said final coefficient of friction is about 0.2 or less.

69. The method of claim 3 wherein said final coefficient of friction is about 0.1 or less.

70. The method of claim 3 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

71. The method of claim 3 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

72. The method of claim 41 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

73. The method of claim 41 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

74. The method of claim 42 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

75. The method of claim 42 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

76. The method of claim 43 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % X in relation to chromium content.

77. The method of claim 43 wherein said sufficient quantity comprises about 25 atomic % X in relation to chromium content.

78. The method of claim 67 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

79. The method of claim 68 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

80. The method of claim 69 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

81. The method of claim 78 wherein said final hardness is about 15 GPa or more.

82. The method of claim 78 wherein said final hardness is about 20 GPa or more.

83. The method of claim 78 wherein said final hardness is about 25 GPa or more.

84. The method of claim 79 wherein said final hardness is about 15 GPa or more.

85. The method of claim 79 wherein said final hardness is about 20 GPa or more.

86. The method of claim 79 wherein said final hardness is about 25 GPa or more.

87. The method of claim 80 wherein said final hardness is about 15 GPa or more.

88. The method of claim 81 wherein said final hardness is about 20 GPa or more.

89. The method of claim 81 wherein said final hardness is about 25 GPa or more.

90. A method of forming a lubricious outer surface comprising chromium, said method comprising:

providing a substrate comprising a surface comprising chromium, said surface having an initial coefficient of friction in an unlubricated condition against a steel counterface;

treating said surface with an additive comprising oxygen under conditions effective to produce a mixture comprising chromium-oxide molecules and substrate molecules adjacent to said lubricious outer surface consisting essentially of oxide molecules comprising chromium oxide;

wherein said lubricous outer surface has a final coefficient of friction in an unlubricated condition against a steel counterface that is less than said initial coefficient of friction.

91. The method of claim 90 wherein said final coefficient of friction of said surface is about 0.3 or less.

92. The method of claim 90 wherein said final coefficient of friction of said surface is about 0.2 or less.

93. The method of claim 90 wherein said final coefficient of friction of said surface is about 0.1 or less.

94. The method of claim 90 wherein said additive is selected from the group consisting of carbon monoxide, carbon dioxide, formic acid, methyl alcohol, ethyl alcohol, and acetone.

95. The method of claim 90 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

96. The method of claim 90 wherein said sufficient quantity comprises about 25 atomic % substituent in relation to chromium content.

97. The method of claim 91 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

98. The method of claim 91 wherein said sufficient quantity comprises about 25 atomic % substituent in relation to chromium content.

99. The method of claim 92 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

100. The method of claim 92 wherein said sufficient quantity comprises about 25 atomic % substituent in relation to chromium content.

101. The method of claim 93 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

102. The method of claim 94 wherein said sufficient quantity comprises about 25 atomic % substituent in relation to chromium content.

103. The method of claim 94 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % substituent in relation to chromium content.

104. The method of claim 90 wherein said sufficient quantity comprises about 25 atomic % substituent in relation to chromium content.

105. The method of claim 90 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

106. The method of claim 91 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

107. The method of claim 92 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

108. The method of claim 93 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

109. The method of claim 94 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

110. The method of claim 105 wherein said final hardness is about 15 GPa or more.

111. The method of claim 105 wherein said final hardness is about 20 GPa or more.

112. The method of claim 105 wherein said final hardness is about 25 GPa or more.

113. The method of claim 106 wherein said final hardness is about 15 GPa or more.

114. The method of claim 106 wherein said final hardness is about 20 GPa or more.

115. The method of claim 106 wherein said final hardness is about 25 GPa or more.

116. The method of claim 107 wherein said final hardness is about 15 GPa or more.

117. The method of claim 107 wherein said final hardness is about 20 GPa or more.

118. The method of claim 107 wherein said final hardness is about 25 GPa or more.

119. The method of claim 108 wherein said final hardness is about 15 GPa or more.

120. The method of claim 108 wherein said final hardness is about 20 GPa or more.

121. The method of claim 108 wherein said final hardness is about 25 GPa or more.

122. The method of claim 109 wherein said final hardness is about 15 GPa or more.

123. The method of claim 109 wherein said final hardness is about 20 GPa or more.

124. The method of claim 109 wherein said final hardness is about 25 GPa or more.

125. A method of forming a hard surface comprising chromium, said method comprising:

providing a substrate comprising chromium comprising a surface having an initial hardness;

treating said surface with an additive comprising an element selected from the group consisting of oxygen, carbon, and a combination thereof under conditions effective to produce a final surface having a final hardness greater than said initial hardness, said final surface comprising a mixture comprising substrate molecules and molecules selected from the group consisting of chromium oxide, chromium carbide, and a combination thereof, said mixture being adjacent to an outer surface consisting esentially of oxides comprising chromium oxide.

126. The method of claim 125 wherein said additive is selected from the group consisting of carbon monoxide, carbon dioxide, formic acid, methyl alcohol, ethyl alcohol, and acetone.

127. The method of claim 125 wherein said additive is selected from the group consisting of carbon monoxide ions and carbon dioxide ions.

128. The method of claim 125 wherein said additive is carbon monoxide ions.

129. The method of claim 125 wherein said final hardness is about 15 GPa or more.

130. The method of claim 125 wherein said final hardness is about 20 GPa or more.

131. The method of claim 125 wherein said final hardness is about 25 GPa or more.

132. The method of claim 126 wherein said final hardness is about 15 GPa or more.

133. The method of claim 126 wherein said final hardness is about 20 GPa or more.

134. The method of claim 126 wherein said final hardness is about 25 GPa or more.

135. The method of claim 127 wherein said final hardness is about 15 GPa or more.

136. The method of claim 127 wherein said final hardness is about 20 GPa or more.

137. The method of claim 127 wherein said final hardness is about 25 GPa or more.

138. The method of claim 128 wherein said final hardness is about 15 GPa or more.

139. The method of claim 128 wherein said final hardness is about 20 GPa or more.

140. The method of claim 128 wherein said final hardness is about 25 GPa or more.

141. A method for making a medical implant comprising:

providing a component of a medical implant comprising a substrate comprising a surface comprising chromium, said surface having an initial coefficient of friction in an unlubricated condition against a steel counterface;

treating said surface with an additive comprising oxygen under conditions effective to produce a mixture comprising substrate molecules and chromium-oxide molecules adjacent to a lubricious outer surface consisting essentially of oxide molecules comprising chromium oxide, said surface having a final coefficient of friction in an unlubricated condition against a steel counterface that is less than said initial coefficient of friction.

142. The method of claim 141 wherein said final coefficient of friction of said surface is about 0.3 or less.

143. The method of claim 141 wherein said final coefficient of friction of said surface is about 0.2 or less.

144. The method of claim 141 wherein said final coefficient of friction of said surface is about 0.1 or less.

145. The method of claim 141 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % oxygen in relation to chromium content.

146. The method of claim 141 wherein said sufficient quantity comprises about 25 atomic % oxygen in relation to chromium content.

147. The method of claim 142 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % oxygen in relation to chromium content.

148. The method of claim 142 wherein said sufficient quantity comprises about 25 atomic % oxygen in relation to chromium content.

149. The method of claim 143 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % oxygen in relation to chromium content.

150. The method of claim 143 wherein said sufficient quantity comprises about 25 atomic % oxygen in relation to chromium content.

151. The method of claim 144 wherein said sufficient quantity comprises from about 10 atomic % to about 40 atomic % oxygen in relation to chromium content.

152. The method of claim 144 wherein said sufficient quantity comprises about 25 atomic % oxygen in relation to chromium content.

153. The method of claim 141 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

154. The method of claim 142 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

155. The method of claim 143 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

156. The method of claim 144 wherein said surface comprises an initial hardness and said conditions are effective to produce a final hardness that is greater than said initial hardness.

157. The method of claim 141 wherein said final hardness is about 15 GPa or more.

158. The method of claim 141 wherein said final hardness is about 20 GPa or more.

159. The method of claim 141 wherein said final hardness is about 25 GPa or more.

160. The method of claim 142 wherein said final hardness is about15 GPa or more.

161. The method of claim 142 wherein said final hardness is about 20 GPa or more.

162. The method of claim 142 wherein said final hardness is about 25 GPa or more.

163. The method of claim 143 wherein said final hardness is about 15 GPa or more.

164. The method of claim 143 wherein said final hardness is about 20 GPa or more.

165. The method of claim 143 wherein said final hardness is about 25 GPa or more.

166. The method of claim 144 wherein said final hardness is about 15 GPa or more.

167. The method of claim 144 wherein said final hardness is about 20 GPa or more.

168. The method of claim 144 wherein said final hardness is about 25 GPa or more.

169. A substrate comprising chromium and a gradient from an inside to an outside surface consisting essentially of:

substrate molecules/a mixture of said substrate molecules and substrate-X molecules comprising chromium-X/a surface comprising a sufficient quantity of said chromium-X molecules to produce a final coefficient of friction in an unlubricated condition against a steel counterface that is less than a virgin coefficient of friction of said surface in the absence of said gradient;

wherein X is selected from the group consisting of fluorine, oxygen, sulfur, and chlorine.

170. The substrate of claim 169 wherein X is fluorine.

171. The substrate of claim 169 wherein X is sulfur.

172. The substrate of claim 169 wherein said gradient further comprises chromium carbide molecules.

173. The substrate of claim 170 wherein said gradient further comprises chromium carbide molecules.

174. The substrate of claim 171 wherein said gradient further comprises chromium carbide molecules.

175. A chromium coating comprising a gradient from inside to an outside surface consisting essentially of:

180. The method of claim 174 wherein said chromium coating comprises in initial hardness, and said means for reducing said initial coefficient of friction further comprises means for increasing said initial hardness.

181. A chromium coating comprising

a surface comprising chromium oxide having an initial coefficient of friction

in an unlubricated condition against a steel counterface; and

means for reducing said initial coefficient of friction.

182. The chromium coating of claim 176 further comprising in initial hardness, said means for reducing said initial coefficient of friction further comprising means for increasing said initial hardness.

183. A chromium alloy substrate comprising

a surface comprising chromium oxide having an initial coefficient of friction

in an unlubricated condition against a steel counterface; and

means for reducing said initial coefficient of friction.

184. The chromium alloy substrate of claim 178 further comprising in initial hardness, said means for reducing said initial coefficient of friction further comprising means for increasing said initial hardness.

185. A method of forming a hard chromium coating comprising:

providing a chromium coating having an initial hardness; and

means for increasing said initial hardness.

186. The method of claim 180 wherein said means for reducing said initial hardness further comprises means for decreasing said initial coefficient of friction.

187. A chromium coating comprising

a surface comprising chromium oxide having an initial hardness; and

means for increasing said initial hardness.

188. The chromium coating of claim 187 wherein said means for reducing said initial hardness further comprises means for decreasing said initial coefficient of friction.

189. A substrate comprising a chromium coating comprising:

a gradient consisting essentially of primarily chromium/a mixture of chromium-X molecules and chromium molecules/a surface comprising a sufficient quantity of said chromium-X molecules to produce a final coefficient of friction in an unlubricated condition against a steel counterface that is less than a virgin coefficient of friction of said surface in the absence of said gradient;

X being selected from the group consisting of fluorine, oxygen, sulfur, and chlorine.

190. The substrate of claim 189 wherein X is fluorine.

191. The substrate of claim 189 wherein X is sulfur.

192. A substrate comprising a chromium coating comprising a gradient from inside to an outside surface consisting essentially of:

primarily chromium molecules/a mixture of chromium oxide molecules and chromium molecules/a surface comprising a sufficient quantity of said chromium oxide molecules to produce a final coefficient of friction in an unlubricated condition against a steel counterface that is less than a virgin coefficient of friction of said surface in the absence of said gradient.

193. The substrate of claim 192 wherein said gradient further comprises chromium carbide molecules.

194. The substrate of claim 192 comprising an automotive component.

195. The substrate of claim 192 comprising an aeronautical component.

196. The substrate of claim 192 comprising a journal bearing.

197. The substrate of claim 192 comprising a tool for injection molding of filled polymers.

198. The substrate of claim 192 wherein said tool is selected from the group consisting of a plated mold and a runner block.

199. A medical implant comprising a gradient from inside to an outside surface consisting essentially of:

chromium alloy molecules/a mixture comprising chromium alloy molecules and chromium oxide molecules/a surface comprising a sufficient quantity of said chromium oxide molecules to produce a final coefficient of friction in an unlubricated condition against a steel counterface that is less than a virgin coefficient of friction of said surface in the absence of said gradient.

200. The medical implant of claim 199 wherein said gradient further comprises chromium carbide molecules.

201. The medical implant of claim 199 comprising a total joint replacement.

202. The medical implant of claim 200 comprising a total joint replacement.

203. A medical implant comprising a gradient from inside to an outside surface consisting essentially of:

a surface comprising chromium oxide having an initial coefficient of friction in an unlubricated condition against a steel counterface; and

means for reducing said initial coefficient of friction.

204. The medical implant of claim 169 further comprising means for increasing an initial hardness of said surface.

205. The medical implant of claim 202 comprising a total joint replacement.

206. The medical implant of claim 203 comprising a total joint replacement.